PICKUP LENS

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to a pickup lens suitable for

5   mounting in a camera which uses a CCD or CMOS device as a

pickup element.

Description of Related Art

One characteristic of this pickup lens is a short optical

length. Another characteristic is that various aberrations

10   thereof are corrected to amounts sufficiently small that

distortion of the image formed by this pickup lens is not

recognized by visual perception, and sufficiently small as to

satisfy the requirements of the integration density of the

pickup element. Below, "various aberrations are corrected to

15   amounts sufficiently small that distortion of the image formed

by this pickup lens is not recognized by visual perception,

and sufficiently small as to satisfy the requirements of the

integration density of the pickup element" is, for simplicity,

represented by the phrase "various aberrations are

20   satisfactorily corrected" or similar. An image for which

various aberrations are satisfactorily corrected may be called

a "satisfactory image".

A pickup lens mounted in a compact camera which uses a

CCD or CMOS device as a pickup element must have a short

25   optical length, and must be able to be manufactured at low

cost. One such lens is, for example, the pickup lens

disclosed in Japanese Patent Laid-open No. 11-38316. However,

although the pickup lens disclosed in this publication comprises few components, which number four elements in four groups, the first lens, which is the initial lens approaching from the object side, is very thick and so difficult to

5 machine. As a result, manufacturing costs are increased and productivity is poor. Moreover, the optical length exceeds 10 mm, so that the optical length is too long for a lens mounted in a compact camera which uses a CCD or CMOS device as a pickup element.

10 This invention has as an object the provision of a pickup lens in which various aberrations are satisfactorily corrected, which can be manufactured at low cost, and which has an optical length of 10 mm or less.

SUMMARY OF THE INVENTION

15 A pickup lens of this invention which achieves the above object has a four-element, four-group configuration, in which are arranged, in order from the object side, a first lens L_1, an aperture diaphragm S, a second lens L_2, a third lens L_3, and a fourth lens L_4. The first lens L_1 is a meniscus-shape lens

20 with negative refractive power, arranged with concave face on the object side. The second lens L_2 is a lens with convex faces on both the object side and the image side, and having positive refractive power. The third lens L_3 is a lens with concave faces on both the object side and the image side, and

25 having negative refractive power. The fourth lens L_4 is a lens with convex faces on both the object side and the image side, and having positive refractive power.

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Among all the eight lens faces forming these first
through fourth lenses (each lens has one curved surface on
each of the object and the image sides, so that the total
number of faces for the four lenses is eight), at least three
5 lens faces are aspherical and satisfy the following conditions.

$$+5.0 < (r_2+r_1)/(r_2-r_1) < +7.0 \qquad (1)$$

$$0.15f < d_1 < 0.3f \qquad (2)$$

Here r_1 is the radius of curvature in the vicinity of the
optical axis of the face on the object side of the first lens
10 (axial radius of curvature); r_2 is the radius of curvature in
the vicinity of the optical axis of the face on the image side
of the first lens (axial radius of curvature); d_1 is the
thickness of the first lens; and f is the focal length of the
entire system (the combined focal length of the lens system
15 comprising the first, second, third, and fourth lenses).

So-called bending operations can be performed in which,
by changing both the radii of curvature r_1 and r_2 of the first
lens, aberrations alone can be changed without changing the
lens focal length. Under conditions such that the lens focal
20 length does not change, the value of q given by $q=(r_2+r_1)/(r_2-r_1)$ when r_1 and r_2 are changed is called the lens shape factor,
and is a parameter representing the degree of bending. That
is, the parameter q is 0 for a symmetrical lens ($r_1=-r_2$), and
becomes larger as the lens becomes more asymmetrical. and so
25 is a parameter representing the extent of deviation from a
symmetrical lens (the extent of asymmetry).

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Hence the above condition equation (1) means that the parameter q, which represents the extent of bending of the first lens, should be set within the range +5.0 to +7.0.

By having the lenses which are components satisfy the conditions stipulated by equation (1) and equation (2), and moreover by positioning the lenses in the above-described configuration, a pickup lens can be provided which can be manufactured at low cost, which has an optical length of 10 mm or less, and in which various aberrations can be satisfactorily corrected.

In the case of a pickup lens with a short combined focal length f of 3.3 mm to 4.0 mm, a back focus of approximately several millimeters must be secured. By making the negative refractive power of the first lens large, an adequate back focus can be secured.

By means of the negative lens element which is the third lens, axial chromatic aberration and lateral chromatic aberration can be satisfactorily corrected.

Equation (1) is a condition for obtaining sufficient back focus while maintaining a satisfactory image. If the radii of curvature r_1 and r_2 are set to exceed the upper limits, the meridional plane of astigmatism curves too far in the positive direction. Also, if the radii of curvature r_1 and r_2 are set below the lower limits, the back focus becomes short and the angle of the ray incident on the CCD imaging surface becomes an acute angle. Consequently total reflection occurs due to the microlens at the peripheral portion of the image, so that

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the peripheral portion of the image becomes dark. In addition,

the meridional plane of astigmatism curves too far in the

negative direction.

By positioning a diaphragm between the first lens and the

5   second lens, negative distortion aberration (barrel

distortion) in the second and fourth lenses placed thereafter

can be corrected.

Equation (2) gives the condition for correction of

curvature of field, while maintaining a short total length for

10   the lens system and a small diameter for the first lens. If

the thickness d_1 of the first lens exceeds the upper-limit

thickness, the total lens length and the first lens diameter

become too great, and compactness of the lens system is lost.

Also, the negative distortion aberration increases. If d_1 is

15   smaller than the lower limit of equation (2), so that the lens

thickness is reduced, the curvature of field increases, which

is also undesirable. Also, if d_1 is decreased below the lower

limit of equation (2), and a plastic lens is used, it will be

difficult to shape the lens according to design.

20   As is clear in Embodiment 1 and Embodiment 2 described

below, by means of the two conditions given by equation (1)

and equation (2), a pickup lens with excellent productivity,

in which various aberrations are satisfactorily corrected, and

with an optical length of 10 mm or less, can be realized.

25   Further, it is preferable that a pickup lens of this

invention be formed from component lenses all of which are of

a plastic material (a polymer material which can be molded and

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shaped by plastic deformation under the application of heat or pressure, or both, and which is transparent to visible light).

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, features and advantages of the present invention will be better understood from the following description taken in connection with the accompanying drawings, in which:

Fig. 1 is a summary cross-sectional view to explain the configuration of a pickup lens of this invention;

Fig. 2 is a summary cross-sectional view to explain a first embodiment of a pickup lens of this invention;

Fig. 3 is a graph of distortion aberration of the pickup lens of Fig. 2;

Fig. 4 is a graph of astigmatic aberration of the pickup lens of Fig. 2;

Fig. 5 is a graph of chromatic/spherical aberration of the pickup lens of Fig. 2;

Fig. 6 is a summary cross-sectional view to explain a second embodiment of a pickup lens of this invention;

Fig. 7 is a graph of distortion aberration of the pickup lens of Fig. 6;

Fig. 8 is a graph of astigmatic aberration of the pickup lens of Fig. 6;

Fig. 9 is a graph of chromatic/spherical aberration of the pickup lens of Fig. 6;

Fig. 10 is a summary cross-sectional view to explain a first comparative example of a pickup lens of this invention;

Fig. 11 is a graph of distortion aberration of the pickup lens of Fig. 10;

Fig. 12 is a graph of astigmatic aberration of the pickup lens of Fig. 10;

Fig. 13 is a graph of chromatic/spherical aberration of the pickup lens of Fig. 10;

Fig. 14 is a summary cross-sectional view to explain a second comparative example of a pickup lens of this invention;

Fig. 15 is a graph of distortion aberration of the pickup lens of Fig. 14;

Fig. 16 is a graph of astigmatic aberration of the pickup lens of Fig. 14; and,

Fig. 17 is a graph of chromatic/spherical aberration of the pickup lens of Fig. 14.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Below aspects of this invention are explained, referring to the drawings. These drawings merely show in summary the shapes, sizes, and positional relations of components to an extent enabling an understanding of this invention, and the numerical and other conditions explained below are merely suitable examples; the present invention is not limited only to the aspects of the invention.

Embodiments

Fig. 1 is a diagram of the configuration of a pickup lens of this invention.

The first, second, third, and fourth lenses, counting from the object side, are represented by L_1, L_2, L_3, and L_4,

respectively. The pickup surface (light-receiving surface of the solid-state pickup element) is represented by 10, the cover glass separating the pickup surface and the lens system is represented by 12, and the two diaphragm planes are represented, in order from the image side to the object side, by 14 and 16 respectively.

The parameters r_i (i=1, 2, 3, ..., 12) and d_i (i=1, 2, 3, ..., 12) shown in the figure and other parameters are given as specific numerical values in Table 1 through Table 4 below. The subscripts i=1, 2, ..., 12 are assigned to the lens surface numbers, or to lens thicknesses or intervals between lens surfaces, in order from the object side to the image side.

That is, r_i is the radius of curvature of the ith surface (for an aspherical surface, the radius of curvature on the axis); d_i is the distance from the ith surface to the i+1th surface; N_i is the refractivity of the lens media from the ith surface to the i+1th surface; and, v_i is the dispersion of the lens media from the ith surface to the i+1th surface.

Aspherical data is shown, together with surface numbers, in the right-hand columns of Table 1 through Table 4. The aperture diaphragms r_3 and r_4, and the cover glasses r_{11} and r_{12} are planar, and so the radius of curvature is indicated as ∞.

An aspherical surface used in this invention is represented by the following equation.

$$Z = ch^2 / [1 + [1 - (1+k)c^2h^2] + 1/2] + A_0h^4 + B_0h^6 + C_0h^8 + D_0h^{10}$$

Here Z is the depth from the plane which is tangential at the lens vertex, c is the curvature of the surface in the

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vicinity of the optical axis, h is the height from the optical axis, k is the conic constant, A_0 is the fourth-order aspheric coefficient, B_0 is the sixth-order aspheric coefficient, C_0 is the eighth-order aspheric coefficient, and D_0 is the tenth-

5   order aspheric coefficient.

In each of Table 1 through Table 4 in this Specification, in representations of numerical values indicating aspheric coefficients, "e-1" means "10^{-1}". Moreover, a value shown as a focal length f is the combined focal length of the lens system

10   comprising the first, second, third, and fourth lenses.

The first and second embodiments are explained below, referring to Fig. 2 through Fig. 9. Also, two comparative examples (a first comparative example and a second comparative example) which do not satisfy the conditions indicated by the

15   following equation (1) are explained, referring to Fig. 10 through Fig. 17.

$$+5.0 < (r_2+r_1)/(r_2-r_1) < +7.0 \qquad (1)$$

That is, in the first comparative example, $r_1=-2.25$ and $r_2=-3.40$ (see Table 3), so that $(r_2+r_1)/(r_2-r_1) = 4.913$, below

20   the lower limit; and in the second comparative example, $r_1=-2.55$ and $r_2=-3.30$ (see Table 4), so that $(r_2+r_1)/(r_2-r_1) = 7.800$, above the upper limit.

Fig. 2, Fig. 6, Fig. 10 and Fig. 14 show summary cross-sectional views of lens configurations and respective spot

25   diagrams, indicating the extent of spreading of the point image in the image plane with respect to the distance of incidence. In these drawings, the spot images are drawn

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surrounded by a rectangle on the right side of the pickup

plane 10 (light-receiving surface of the solid-state pickup

element) which is long in the vertical direction, showing the

extent of spreading of the point image projected on the pickup

5   plane 10 to correspond to the size of a circle.   Distortion

aberration curves are shown in Fig. 3, Fig. 7, Fig. 11 and Fig.

15, astigmatic aberration curves in Fig. 4, Fig. 8, Fig. 12

and Fig. 16, and chromatic/spherical aberration in Fig. 5, Fig.

9, Fig. 13 and Fig. 17.

10   A distortion aberration curve shows the aberration amount

(the amount by which the tangent condition is not satisfied,

expressed as a percentage along the horizontal axis) versus

the distance from the optical axis (expressed as a percentage

along the vertical axis, with the maximum distance from the

15   optical axis within the image plane equal to 100).   An

astigmatic aberration curve shows the amount of aberration

along the horizontal axis (in mm units) for a distance from

the optical axis, similarly to a distortion aberration curve.

Astigmatism was represented as aberration amounts (in mm

20   units) in the meridional plane and in the sagittal plane.   A

chromatic/spherical aberration curve shows the amount of

aberration along the horizontal axis (in mm units) for a

distance of incidence h (F number).   In a chromatic/spherical

aberration curve, aberration amounts are shown for the C line

25   (light of wavelength 656.27 nm), the d line (light of

wavelength 587.56 nm), and the g line (light of wavelength

435.84 nm).   The refractivity is the refractivity for the d

line (light of wavelength 587.56 nm).

    Below, the radii of curvature of component lenses (mm

units), intervals between lenses (mm units), refractivity of

5 lens materials, Abbe number of lens materials, focal length,

numerical aperture, and aspheric coefficients are listed for

the first embodiment (Table 1), second embodiment (Table 2),

first comparative example (Table 3), and second comparative

example (Table 4).

Table 1

Radius of Curvature (r_i)	Distance(d_i)	Refractivity (N_i)	Abbe Number(ν_i)	Aspheric Coefficient				
				k	A_0	B_0	C_0	D_0
$r_1 = -1.72$	$d_1 = 0.72$	$N_1 = 1.53$	$\nu_1 = 56.0$	0.104	0.522e-2	0.791e-2	-0.6954e-2	0.4333e-2
$r_2 = -2.53$	$d_2 = 0.35$			0	-0.6185e-1	0.1315e-1	0.2472e-1	-0.144e-1
$r_3 = \infty$	$d_3 = 0.05$	Aperture Diaphragm						
$r_4 = \infty$	$d_4 = 0.04$							
$r_5 = 1.46$	$d_5 = 0.81$	$N_5 = 1.53$	$\nu_5 = 56.0$	0	-0.5248e-1	0.2277e-2	0.77e-1	-0.3259e-1
$r_6 = -2.70$	$d_6 = 0.27$			0	0.4753e-1	0.46e-1	-0.9776e-2	0.1911e-1
$r_7 = -1.23$	$d_7 = 0.63$	$N_7 = 1.583$	$\nu_7 = 30.0$	0	0.1339	0.2823e-1	0.205e-1	-0.4348e-1
$r_8 = 2.38$	$d_8 = 0.036$							
$r_9 = 2.375$	$d_9 = 1.40$	$N_9 = 1.53$	$\nu_9 = 56.0$	-0.5752	0.5063e-1	0.4741e-2	-0.2453e-3	0.6564e-3
$r_{10} = -2.11$	$d_{10} = 0.7574$							
$r_{11} = \infty$	$d_{11} = 0.60$	$N_{11} = 1.523$ Cover Glass						
$r_{12} = \infty$	$d_{12} = 1.00$							

Focal Length f = 3.315 mm
Numerical Aperture Fno = 3.30

Table 2

Radius of Curvature (r_i)	Distance (d_i)	Refractivity (N_i)	Abbe Number (ν_i)	Aspheric Coefficient				
				k	A_0	B_0	C_0	D_0
$r_1 = -2.45$	$d_1 = 0.90$	$N_1 = 1.53$	$\nu_1 = 56.0$	-0.2277	0.1506e-1	-0.1981e-2	-0.9393e-3	0.2354e-3
$r_2 = -3.35$	$d_2 = 1.25$			0	-0.4867e-3	-0.3141e-2	0.542e-3	-0.2214e-6
$r_3 = \infty$	$d_3 = 0.05$	Aperture Diaphragm						
$r_4 = \infty$	$d_4 = 0.07$							
$r_5 = 1.821$	$d_5 = 0.85$	$N_5 = 1.53$	$\nu_5 = 56.0$	0	-0.1278e-1	0.9956e-3	-0.4357e-2	0.2534e-2
$r_6 = -5.661$	$d_6 = 0.30$			0	-0.9681e-2	-0.3167e-2	-0.4366e-2	0.2074e-2
$r_7 = -1.58$	$d_7 = 0.70$	$N_7 = 1.583$	$\nu_7 = 30.0$	0	0.274e-1	0.196e-1	-0.108e-1	0.6145e-2
$r_8 = 2.647$	$d_8 = 0.04$							
$r_9 = 2.647$	$d_9 = 1.70$	$N_9 = 1.53$	$\nu_9 = 56.0$					
$r_{10} = -2.051$	$d_{10} = 1.3958$			-0.2896	0.2136e-1	0.12e-1	-0.2574e-2	0.9287e-3
$r_{11} = \infty$	$d_{11} = 1.00$	$N_{11} = 1.523$	Cover Glass					
$r_{12} = \infty$	$d_{12} = 1.00$							

Focal Length f = 3.812 mm
Numerical Aperture Fno = 2.80

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Table 3

Radius of Curvature (r_i)	Distance(d_i)	Refractivity (N_i)	Abbe Number(ν_i)	k	Aspheric Coefficient			
					A_0	B_0	C_0	D_0
r_1 = -2.25	d_1 = 0.90	N_1 = 1.53	ν_1 = 56.0	-0.2277	0.1506e-1	-0.1981e-2	-0.9393e-3	0.2354e-3
r_2 = -3.40	d_2 = 1.25			0	-0.4867e-3	-0.3141e-2	0.542e-3	-0.2214e-6
r_3 = ∞	d_3 = 0.05	Aperture Diaphragm						
r_4 = ∞	d_4 = 0.07							
r_5 = 1.821	d_5 = 0.85	N_5 = 1.53	ν_5 = 56.0	0	-0.1278e-1	0.9956e-3	-0.4357e-2	0.2534e-2
r_6 = -5.661	d_6 = 0.30			0	-0.9681e-2	-0.3167e-2	-0.4366e-2	0.2074e-2
r_7 = -1.58	d_7 = 0.70	N_7 = 1.583	ν_7 = 30.0	0	0.274e-1	0.196e-1	-0.108e-1	0.6145e-2
r_8 = 2.647	d_8 = 0.04							
r_9 = 2.647	d_9 = 1.70	N_9 = 1.53	ν_9 = 56.0					
r_{10} = -2.051	d_{10} = 1.3958			-0.2896	0.2136e-1	0.12e-1	-0.2574e-2	0.9287e-3
r_{11} = ∞	d_{11} = 1.00	N_{11} = 1.523	Cover Glass					
r_{12} = ∞	d_{12} = 1.00							

Focal Length f = 3.832 mm
Numerical Aperture Fno = 2.80

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Table 4

Radius of Curvature (r_i)	Distance (d_i)	Refractivity (N_i)	Abbe Number (ν_i)	k	Aspheric Coefficient			
					A_0	B_0	C_0	D_0
$r_1 = -2.55$	$d_1 = 0.90$	$N_1 = 1.53$	$\nu_1 = 56.0$	-0.2277	$0.1506e\text{-}1$	$-0.1981e\text{-}2$	$-0.9393e\text{-}3$	$0.2354e\text{-}3$
$r_2 = -3.30$	$d_2 = 1.25$			0	$-0.4867e\text{-}3$	$-0.3141e\text{-}2$	$0.542e\text{-}3$	$-0.2214e\text{-}6$
$r_3 = \infty$	$d_3 = 0.05$	Aperture Diaphragm						
$r_4 = \infty$	$d_4 = 0.07$							
$r_5 = 1.821$	$d_5 = 0.85$	$N_5 = 1.53$	$\nu_5 = 56.0$	0	$-0.1278e\text{-}1$	$0.9956e\text{-}3$	$-0.4357e\text{-}2$	$0.2534e\text{-}2$
$r_6 = -5.661$	$d_6 = 0.30$			0	$-0.9681e\text{-}2$	$-0.3167e\text{-}2$	$-0.4366e\text{-}2$	$0.2074e\text{-}2$
$r_7 = -1.58$	$d_7 = 0.70$	$N_7 = 1.583$	$\nu_7 = 30.0$	0	$0.274e\text{-}1$	$0.196e\text{-}1$	$-0.108e\text{-}1$	$0.6145e\text{-}2$
$r_8 = 2.647$	$d_8 = 0.04$							
$r_9 = 2.647$	$d_9 = 1.70$	$N_9 = 1.53$	$\nu_9 = 56.0$	-0.2896	$0.2136e\text{-}1$	$0.12e\text{-}1$	$-0.2574e\text{-}2$	$0.9287e\text{-}3$
$r_{10} = -2.051$	$d_{10} = 1.3958$							
$r_{11} = \infty$	$d_{11} = 1.00$	$N_{11} = 1.523$	Cover Glass					
$r_{12} = \infty$	$d_{12} = 1.00$							

Focal Length f = 3.799 mm
Numerical Aperture Fno = 2.80

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Below, the characteristics of each of the embodiments are discussed, together with the comparative examples. In the first and second embodiments as well as in the first and second comparative examples, ZEONEX E48R (ZEONEX is a registered trademark, and E48R is a product number, of Nippon Zeon Co., Ltd.), which is a cycloolefin plastic, was employed in the first lens (L_1), which has a meniscus shape with the concave surface facing the object side and with negative refractive power, the second lens (L_2), which has convex surfaces on both the object side and the image side and which has a positive refractive power, and the fourth lens (L_4), which has a convex surface on both the object side and the image side, and has positive refractive power.

The third lens (L_3), having concave surface on both the object side and the image side and with a negative refractive power, adopts a polycarbonate. Both surfaces of the first lens (L_1), both surfaces of the second lens (L_2), the object-side surface of the third lens (L_3), and the image-side surface of the fourth lens (L_4) are aspherical. That is, the number of aspherical surfaces is six in each of the embodiments and comparative examples.

The Abbe number of the ZEONEX E48R which is the material of the first lens (L_1), second lens (L_2) and fourth lens (L_4) is 56, but as a result of simulations it was found that if the Abbe number of the material of these lenses is in the range from 45 to 65, no practical difference occurs in the aberration or other lens performance. The Abbe number of the

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polycarbonate which is the material of the third lens (L_3) is 30, but similarly to the above, it was found that if the Abbe number of this lens material is in the range from 25 to 35, no practical difference occurs in the aberration or other lens

5 performance. That is, it was found that if the Abbe numbers are within the above-described respective ranges, a pickup lens can be realized which achieves the objects of this invention, which are the satisfactory correction of various aberrations of the pickup lens compared with the various

10 aberrations of the pickup lenses of the prior art, and an optical length of 10 mm or less.

Between the lens system and the pickup surface, cover glass is inserted which is 0.60 mm thick in the first embodiment, and is 1.00 mm thick in the second embodiment and

15 in the first and second comparative examples; the various aberrations described below are calculated assuming the existence of this cover glass. That is, this cover glass comprises the surfaces r_{11} and r_{12}, and the parameter d_{11} representing the thickness is $d_{11}=0.60$ mm in the first

20 embodiment, and is $d_{11}=1.00$ mm in the second embodiment and in the first and second comparative examples.

First Embodiment

(A) The focal length for the entire system is f = 3.315 mm.

25 (B) The thickness of the first lens is $d_1 = 0.72$ mm.

(C) The radius of curvature of the object-side surface of the first lens is $r_1 = -1.72$ mm.

(D) The radius of curvature of the image-side surface of the first lens is $r_2 = -2.53$ mm.

Because $(r_2+r_1)/(r_2-r_1) = +5.2469$, this lens system satisfies the condition of equation (1). And, because $0.15f = 0.497$, $d_1 = 0.72$ and $0.3f = 0.9945$, the condition of equation (2) is also satisfied.

Fig. 2 shows the results of ray tracing, and a spot diagram showing the spreading of a point image on the pickup surface. It is seen that there is some spreading of the point image only at the position very close to the angle of field, and that a satisfactory point image is obtained over nearly the entirety of the pickup surface.

The optical length is 6.663 mm, which is less than 10 mm, and a sufficient back focus of 2.357 mm is also secured.

Graphs are shown of the distortion aberration curve 20 in Fig. 3, astigmatic aberration curves (aberration curve 22 for the meridional plane and aberration curve 24 for the sagittal plane) in Fig. 4, and chromatic/spherical aberration curves (aberration curve 26 for the C line, aberration curve 28 for the d line, and aberration curve 30 for the g line; however, there is almost no difference between the aberration curves 26 and 28, which overlap) in Fig. 5. The vertical axes of the aberration curves of Fig. 3 and Fig. 4 show the image height, with 100%, 85%, 70%, 50%, and 30% corresponding respectively to 2.187 mm, 1.859 mm, 1.531 mm, 1.093 mm, and 0.656 mm. The horizontal axis indicates the magnitude of aberration. The

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vertical axis of the aberration curve of Fig. 5 shows the distance of incidence h (F number); the maximum is F2.8.

The distortion aberration is within 2%, the astigmatic aberration is within 0.1 mm, and the chromatic/spherical
5   aberration is less than 0.02 mm. In all cases, the performance necessary for a lens mounted in a compact camera which uses a CCD or CMOS device as the pickup element is secured.

Second Embodiment

10   (A) The focal length for the entire system is f = 3.812 mm.

(B) The thickness of the first lens is d_1 = 0.9 mm.

(C) The radius of curvature of the object-side surface of the first lens is r_1 = -2.45 mm.

15   (D) The radius of curvature of the image-side surface of the first lens is r_2 = -3.35 mm.

Because $(r_2+r_1)/(r_2-r_1)$ = +6.444, this lens system satisfies the condition of equation (1). And, because 0.15f = 0.572, d_1 = 0.9 and 0.3f = 1.144, the condition of equation (2)
20   is also satisfied.

Fig. 6 shows the results of ray tracing, and a spot diagram showing the spreading of a point image on the pickup surface. A satisfactory point image is obtained over the entirety of the pickup surface, including the point image at
25   positions very close to the angle of field.

The optical length is 9.256 mm, which is less than 10 mm, and a sufficient back focus of 3.396 mm is also secured.

Graphs are shown of the distortion aberration curve 32 in Fig. 7, astigmatic aberration curves (aberration curve 34 for the meridional plane and aberration curve 36 for the sagittal plane) in Fig. 8, and chromatic/spherical aberration curves

5 (aberration curve 38 for the C line, aberration curve 40 for the d line, and aberration curve 42 for the g line) in Fig. 9. The vertical axes of the aberration curves of Fig. 7 and Fig. 8 show the image height, with 100%, 85%, 70%, 50%, and 30% corresponding respectively to 2.250 mm, 1.913 mm, 1.575 mm,

10 1.125 mm, and 0.675 mm. The vertical axis of the aberration curve of Fig. 9 shows the distance of incidence h (F number); the maximum is F2.8. The horizontal axis shows the magnitude of the aberration. The distortion aberration is within 2.6%, the astigmatic aberration is within 0.08 mm, and the

15 chromatic/spherical aberration is less than 0.05 mm. In all cases, the performance with respect to aberration is that necessary for a lens mounted in a compact camera which uses a CCD or CMOS device as the pickup element.

(First Comparative Example)

20 (A) The focal length for the entire system is f = 3.832 mm.

(B) The thickness of the first lens is d_1 = 0.9 mm.

(C) The radius of curvature of the object-side surface of the first lens is r_1 = -2.25 mm.

25 (D) The radius of curvature of the image-side surface of the first lens is r_2 = -3.40 mm.

Because $(r_2+r_1)/(r_2-r_1) = +4.913$, the value for this lens

system is below the lower limit of the condition of equation

(1), so that the condition is not satisfied.

Fig. 10 shows the results of ray tracing, and a spot

5   diagram showing the spreading of a point image on the pickup

surface. It is seen that spreading of the point image

increases in moving toward the periphery of the pickup surface,

and that a satisfactory point image is not obtained at the

peripheral portion on the pickup surface.

10   The vertical axes of the aberration curves of Fig. 11 and

Fig. 12 show the image height, with 100%, 85%, 70%, 50%, and

30% corresponding respectively to 2.249 mm, 1.911 mm, 1.574 mm,

1.124 mm, and 0.675 mm. The vertical axis of the aberration

curve of Fig. 13 shows the distance of incidence h (F number);

15   the maximum is F2.8. The horizontal axis indicates the

magnitude of aberration.

The distortion aberration is within 0.7%, and the

chromatic/spherical aberration is less than 0.06 mm. However,

the astigmatic aberration is, for an image height of 2.249 mm,

20   2.3 mm in the meridional plane.

The distortion aberration curve 44 shown in Fig. 11 and

the chromatic/spherical aberration curves shown in Fig. 13

(aberration curve 50 for the C line, aberration curve 52 for

the d line, and aberration curve 54 for the g line) indicate

25   satisfactory characteristics; but among the astigmatic

aberration curves shown in Fig. 12 (aberration curve 46 for

the meridional plane, aberration curve 48 for the sagittal

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plane), values in the meridional plane are large (aberration curve 46). In these respects, characteristics are not satisfactory compared with the embodiments.

(Second Comparative Example)

5   (A) The focal length for the entire system is f = 3.799 mm.

(B) The thickness of the first lens is d_1 = 0.9 mm.

(C) The radius of curvature of the object-side surface of the first lens is r_1 = -2.55 mm.

10   (D) The radius of curvature of the image-side surface of the first lens is r_2 = -3.30 mm.

Because $(r_2+r_1)/(r_2-r_1)$ = +7.800, the value for this lens system is above the upper limit of the condition of equation (1), so that the condition is not satisfied.

15   Fig. 14 shows the results of ray tracing, and a spot diagram showing the spreading of a point image on the pickup surface. Similarly to the first comparative example, spreading of the point image increases in moving toward the periphery of the pickup surface, and a satisfactory point

20 image is not obtained at the peripheral portion on the pickup surface.

The vertical axes of the aberration curves of Fig. 15 and Fig. 16 show the image height, with 100%, 85%, 70%, 50%, and 30% corresponding respectively to 2.252 mm, 1.914 mm, 1.576 mm,

25 1.126 mm, and 0.675 mm. The vertical axis of the aberration curve of Fig. 17 shows the distance of incidence h (F number);

the maximum is F2.8. The horizontal axis indicates the magnitude of aberration.

The chromatic/spherical aberration is less than 0.04 mm. However, the distortion aberration is 4.2%, and the astigmatic aberration is, for an image height of 2.252 mm, 0.78 mm in the meridional plane.

The chromatic/spherical aberration curves shown in Fig. 17 (aberration curve 62 for the C line, aberration curve 64 for the d line, and aberration curve 66 for the g line) indicate satisfactory characteristics; but as is seen from the distortion aberration curve 56 shown in Fig. 15 and the astigmatic aberration curves shown in Fig. 16 (aberration curve 58 for the meridional plane, aberration curve 60 for the sagittal plane), the distortion aberration and the astigmatic aberration in the meridional plane (aberration curves 56 and 58) are large. In these respects, characteristics are not satisfactory compared with the embodiments.

Thus from the above embodiments and comparative examples, it is seen that by designing a lens configured so as to satisfy equation (1) and equation (2), which give the conditions under which various aberrations are satisfactorily corrected, a sufficient back focus is obtained, and moreover the optical length is kept short, the problems to be solved by this invention can be solved.

In the embodiments and comparative examples, the plastic materials ZEONEX E48R and polycarbonate were used in the first, second and fourth lenses, and in the third lens, respectively;

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but plastic materials other than those described in the embodiments may be also be used, and in addition, materials other than plastic, such as glass, may of course also be used, so long as the materials satisfy the conditions explained in

5   the embodiments.

As explained above, by means of this invention a pickup lens can be realized which, while comprising only four elements in four groups, enables effective utilization of plastic lenses, achieves satisfactory correction of various

10 aberrations, can be manufactured at low cost, had an optical length of 10 mm or less, and is suitable for use in compact CCD cameras. It is difficult for a pickup lens which utilizes as components lenses employing material with a d-line refractivity of 1.583 and having refractivity wavelength

15 dispersion characteristics with an Abbe number of approximately 30, with all such component lenses formed from optical glass. From another point of view, in the embodiments of this invention, it was possible to present new experimental results demonstrating that even a material having a large

20 wavelength dispersion characteristic with an Abbe number of approximately 30 can be used in the lens configuration method of this invention to form a combination lens enabling satisfactory images.

As explained above, a pickup lens of this invention is

25 suitable for use as, in addition to a lens for a video camera incorporated into a portable telephone, as the lens of a video camera incorporated into a PDA (personal digital assistant),

as the lens of a video camera incorporated into a toy comprising image recognition functions, and as the lens of monitoring video cameras and security video cameras.